Insights on the dynamical history of the Fomalhaut system

Investigating the Fomalhaut c hypothesis

Faramaz et al. 2014, arXiv:1409.6868

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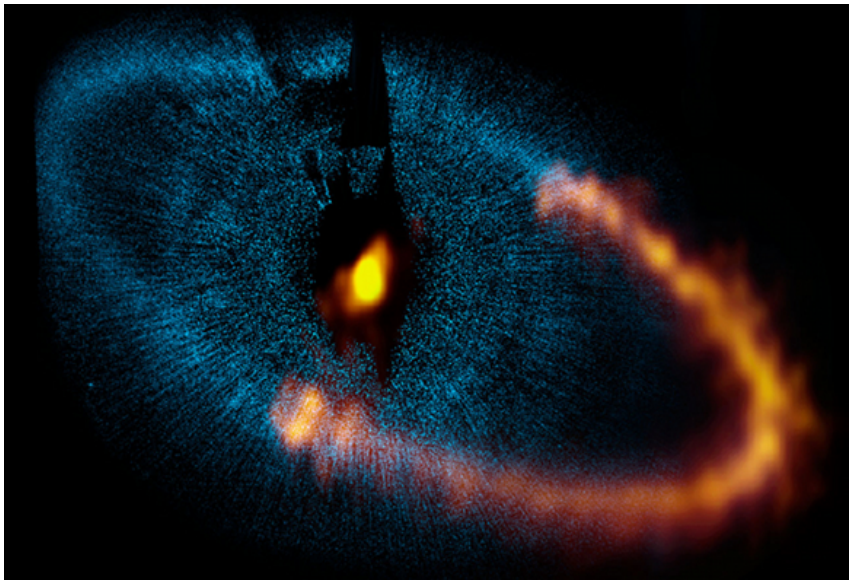
September 2014, 10th

30 years of Beta Pic and Debris disks studies

The Fomalhaut system

An eccentric outer belt

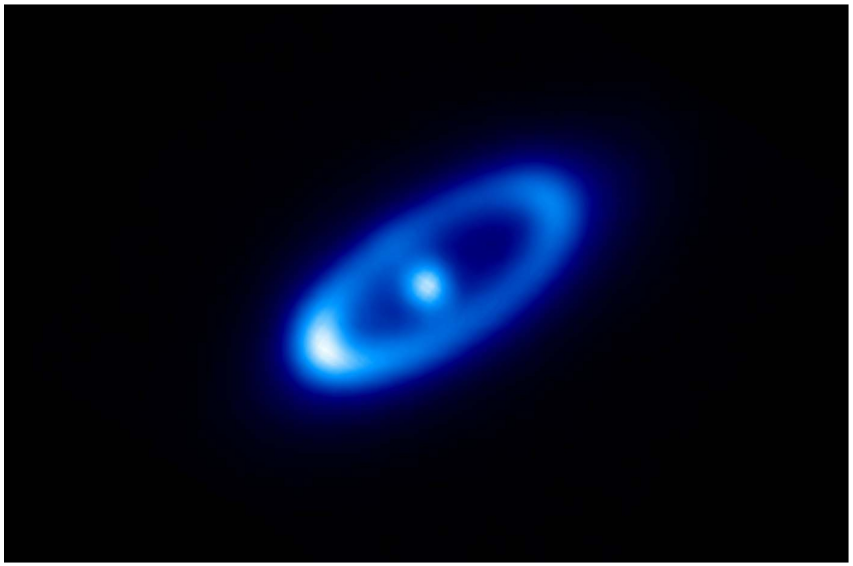


Combined HST (optical) and ALMA (850 microns) observations (Kalas et al. 2005; Boley et al. 2012).

Offseted and eccentric Kuiper-belt with $e \sim 0.1$.

Presence of a belt-shaping massive body with $e \sim 0.1$ expected :

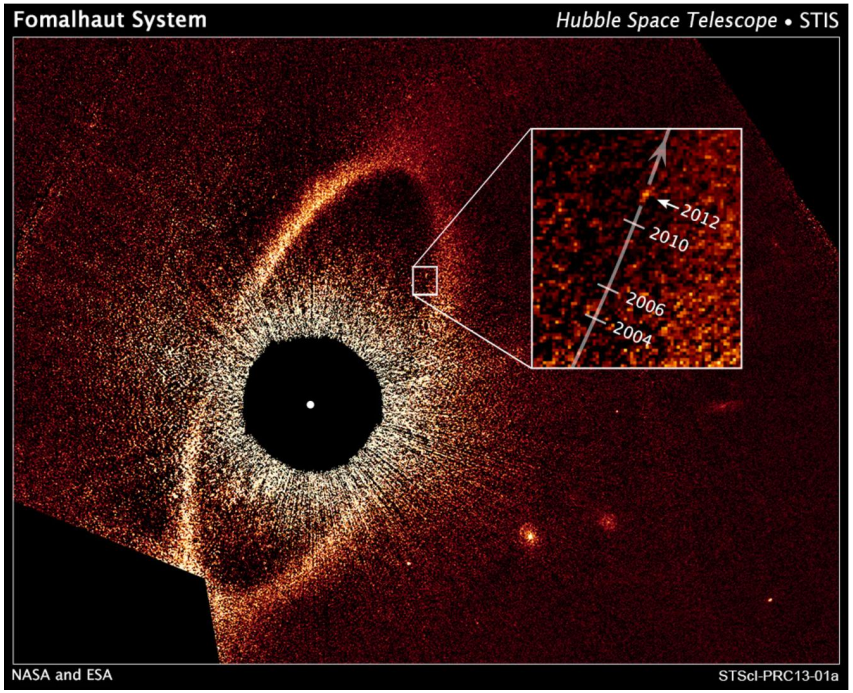
- $m \sim 3\mathrm{M}_{\mathrm{Jup}}$ (Chiang et al. 2009)
- Neptune-Saturn mass (Quillen 2006)



Herschel/PACS observation at 70 microns

The Fomalhaut system

Fomalhaut b, near the belt inner edge



A controversial status

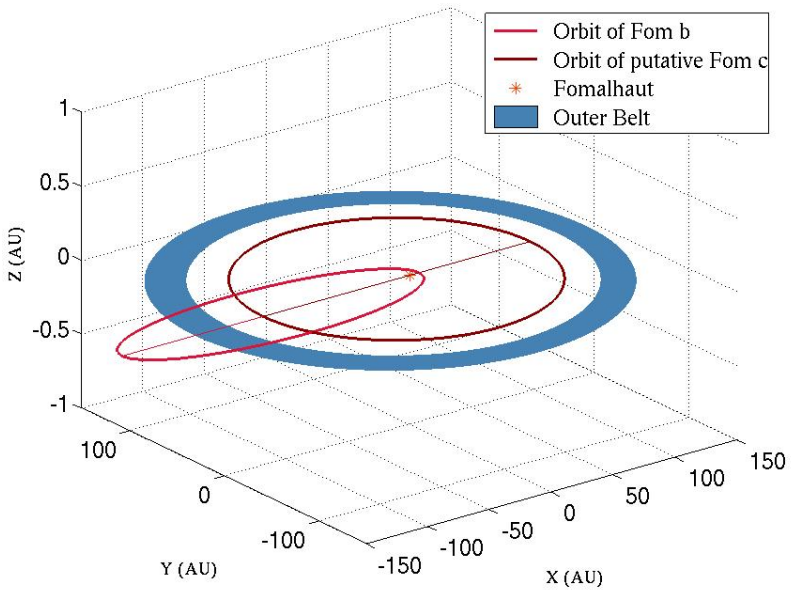
- Observed at visible wavelenths, but undetected in IR (Kalas et al. 2008; Marengo et al. 2009; Janson et al. 2012).
- Planetary body surrounded by dust ? (Kennedy & Wyatt 2011; Kenyon et al. 2014) or a planetary ring system ? (Kalas et al. 2008)
- Recent photometric studies : no more than Earth or Super-Earth sized (Janson et al. 2012; Galicher et al. 2013).

The Fomalhaut system

Fomalhaut b

Orbital fitting (Kalas et al. 2013; Beust et al. 2014)

- Peak values : $a_b \sim 110 - 120\,\mathrm{AU}$ & $e_b \simeq 0.92 - 0.94$.
- 95% level of confidence : $a_b \sim 81 - 415\,\mathrm{AU}$ & $e_b \sim 0.69 - 0.98$.
- Belt-crossing.
- Nearly coplanar and close to apsidal alignment with the belt.



Dynamical analysis :

Fom b is

- a low-mass object,
- not responsible for the shape of the outer belt.

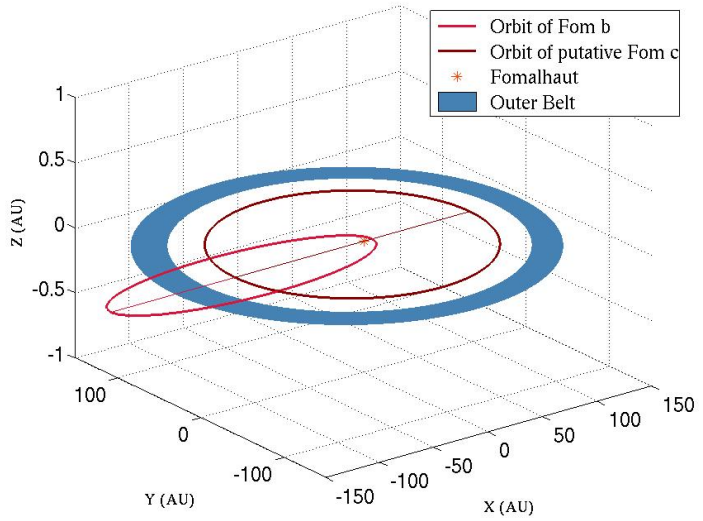
The first suspect is not the culprit here !

The Fomalhaut system

Investigating the Fomalhaut c hypothesis (Faramaz et al. 2014, arXiv :1409.6868)

Clues for an unseen massive Fom c.

$\Downarrow$



Stability ?

- Highly unstable configuration (dynamical lifetime $\ll$ age of the system, 440 Myr).
- Fom b recently set on its orbit.

How ? Why so late ?

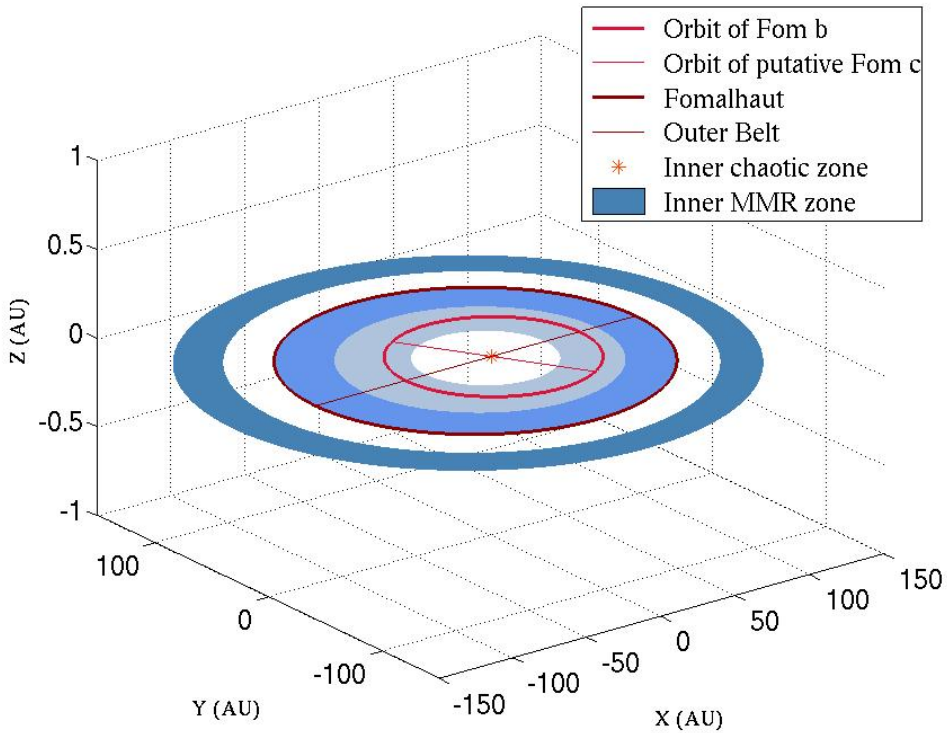
$\Longrightarrow$

A dynamical scenario involving Fom c in the generation of Fom b-like orbits :

- shows that Fom b can be naturally put on its present-day orbit via perturbations by Fom c.
- can explain why it occurs so late and makes it likely for us to witness.

The key mechanism

Mean-motion resonances with an 0.1 eccentric Fom c



Example of Fom b progenitor originally trapped in 5 :2 MMR on a low-eccentricity orbit with a 3 M_{Jup} Fom c : $a_{b,0} \sim 58\,\mathrm{AU}$ and $e_{b,0} \leqslant 0.05$

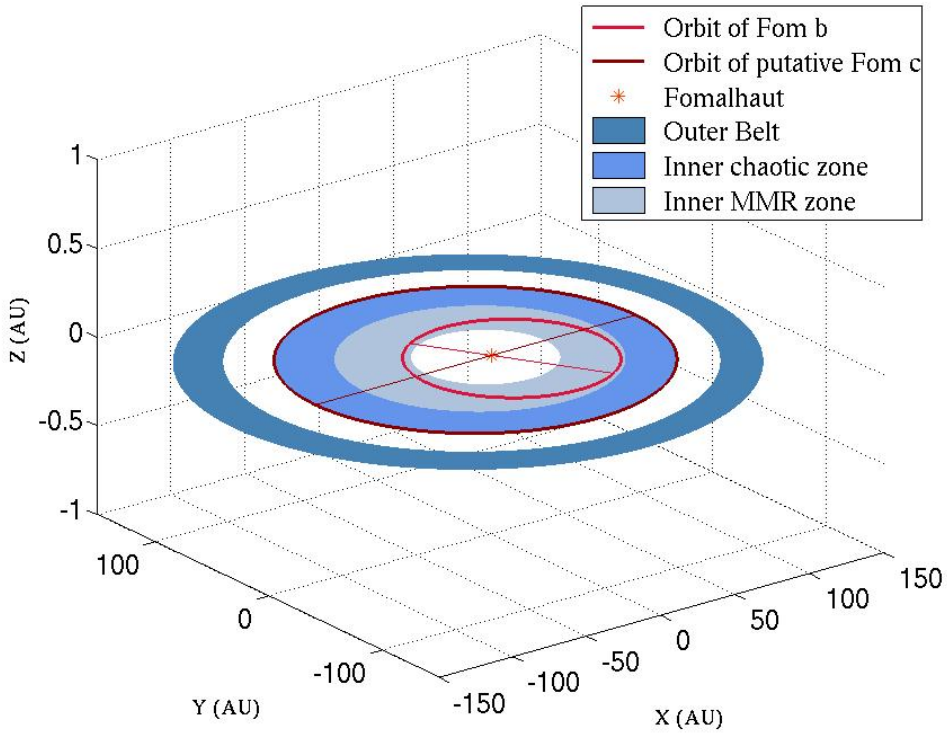
- Increase of eccentricity $\rightarrow$ crossing of the chaotic zone.
- Scattering event in the chaotic zone $\rightarrow$ Fom b-like orbit ?
- MMRs *delay* scattering events.

The delay depends on the mass of Fom c :

- Jupiter mass Fom c $\rightarrow$ delay of several Myr.
- Saturn-Neptune mass Fom c $\rightarrow$ delay of several 100 Myr.

The key mechanism

Mean-motion resonances with an 0.1 eccentric Fom c



Example of Fom b progenitor originally trapped in 5 :2 MMR with a 3 M_{Jup} Fom c : $a_{b,0} \sim 58$ AU and $e_{b,0} \leqslant 0.05$

Eccentricity increase

- Increase of eccentricity $\rightarrow$ crossing of the chaotic zone.
- Scattering event in the chaotic zone $\rightarrow$ Fom b-like orbit ?
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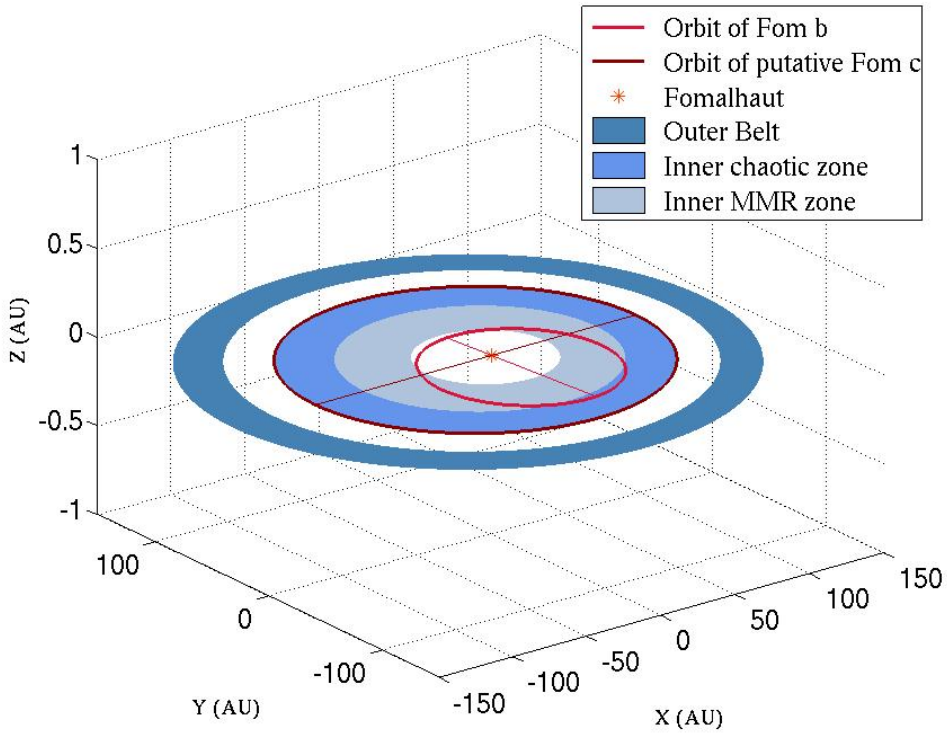
The key mechanism

Mean-motion resonances with an 0.1 eccentric Fom c



Example of Fom b progenitor originally trapped in 5 :2 MMR with a 3 M_{Jup} Fom c : $a_{b,0} \sim 58$ AU and $e_{b,0} \leqslant 0.05$

Crossing the chaotic zone

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The key mechanism

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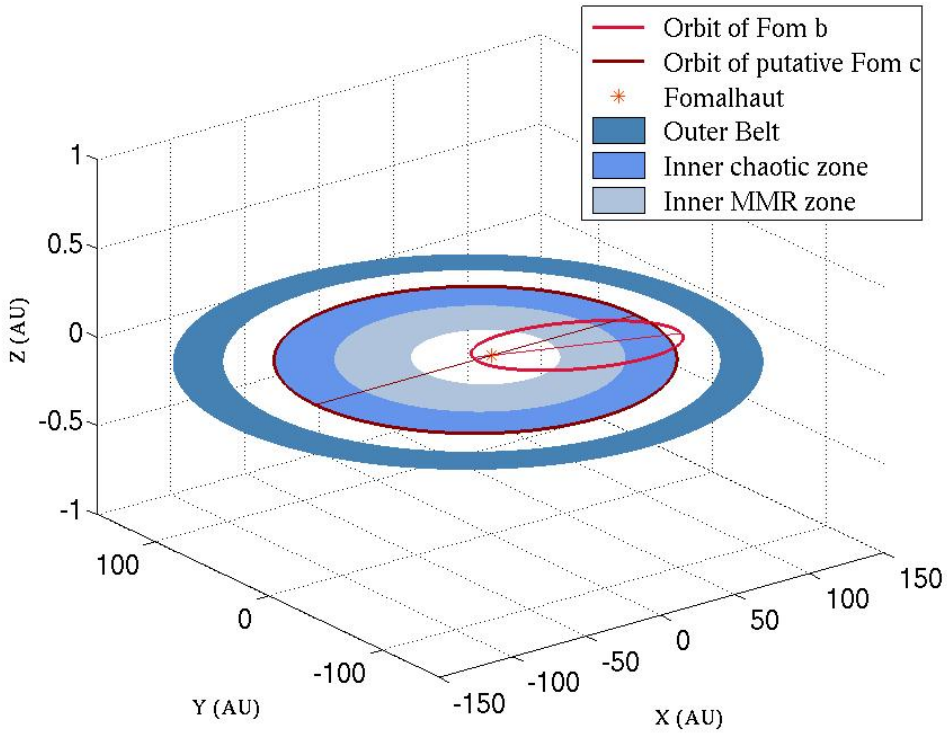


Example of Fom b progenitor originally trapped in 5 :2 MMR with a 3 M_{Jup} Fom c : $a_{b,0} \sim 58$ AU and $e_{b,0} \leqslant 0.05$

Crossing the orbit of Fom c

- Increase of eccentricity $\rightarrow$ crossing of the chaotic zone.
- Scattering event in the chaotic zone $\rightarrow$ Fom b-like orbit ?
- MMRs *delay* scattering events.

The delay depends on the mass of Fom c :

- Jupiter mass Fom c $\rightarrow$ delay of several Myr.
- Saturn-Neptune mass Fom c $\rightarrow$ delay of several 100 Myr.

A 2-step scenario ?

A first summary

1. MMR with an eccentric Fom c
2. Scattering event in the chaotic zone.

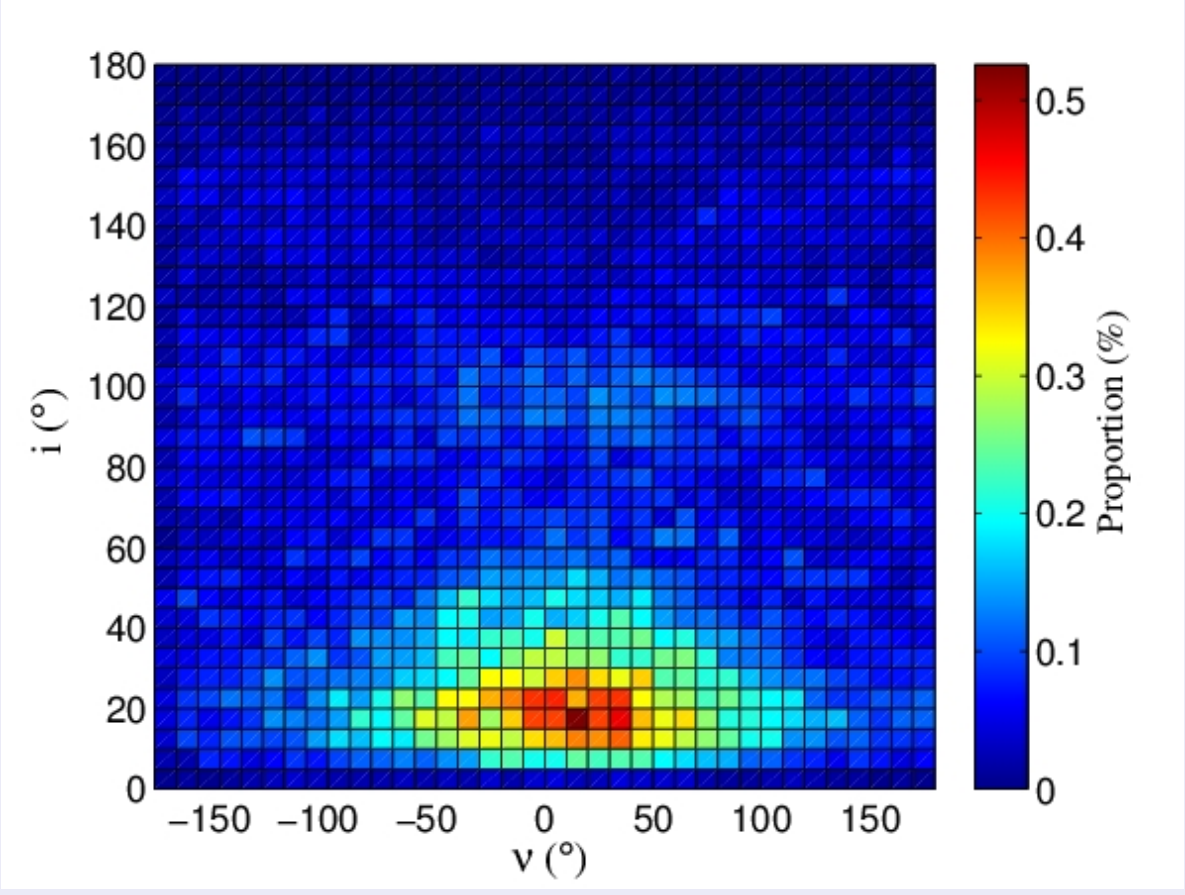
First conclusions

A Saturn-Neptune mass Fom c with eccentricity 0.1 :

- leads to the production of Fom b-like orbits, with a delay of several 100 Myr, via the 5 :2 MMR.
- is compatible with the shaping of the outer belt.
- is compatible with the survival of the present transient configuration for ~ 10 Myr.

A surprising feature

Orientation of Fom b-like orbits originating from the 5 :2 MMRs



Clear tendency for apsidal alignement and coplanarity.

An additional step ?

Closer look at Step 2 : close encounter with Fom c

Step 2 : close encounter with Fom c

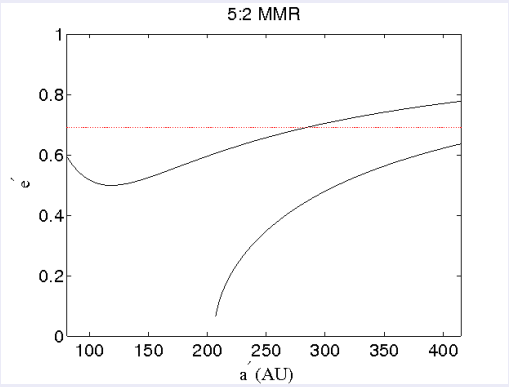
(a, e)

Before encounter :

- a of the MMR
- e allowed by the MMR.

$\longrightarrow$

Conservation of the Tisserand parameter links (a, e) and (a', e')



(a', e')

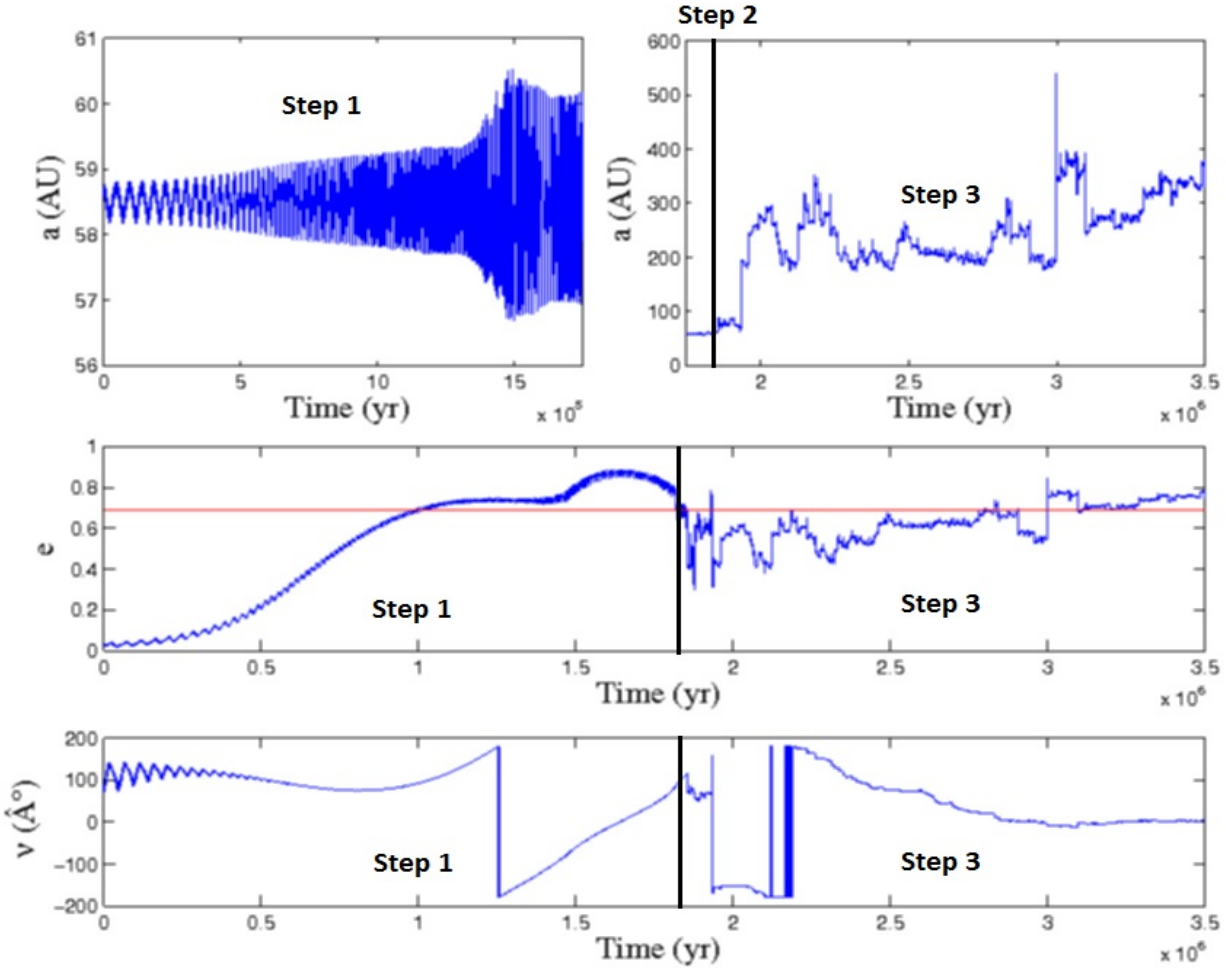
After encounter :

- $a' = 81 - 415$ AU (95% level of confidence for Fom b, Beust et al. 2014)
- $e' < 0.69 \Longrightarrow$ Additional increase required

Step 3 : secular evolution with an eccentric Fom c

Secular evolution permits $e_b > 0.69$ when orbits are apsidally aligned

A 3-step process
Summary



3 Successive interactions with the eccentric Fom c :

- Step 1 :
  MMR
- Step 2 :
  Close-encounter
- Step 3 :
  Secular interaction

Conclusion

A possible dynamical history for the Fomalhaut system

- A yet undetected eccentric Saturn-Neptune size Fom c.
- Fom b originates from an inner MMR with Fom c.
- Fom b was set recently on its current orbit by Fom c via a 3-step process.

Producing Fom b-like orbits is a robust process

Low mass material + massive eccentric planet :
MMR $\rightarrow$ close encounter $\rightarrow$ secular evolution

$\Longrightarrow$ Fom b like orbits - Cometary activity ?

- A 0.1 eccentric perturber naturally produces such orbits in a robust manner.
- The production of these orbits can be delayed on timescales $>$ 100 Myr thanks to MMRs.

Faramaz et al., in prep :

- Link with inner belts in Fomalhaut ? (Lebreton et al. 2013)
- Link with exozodis ?
  (Absil et al. 2013; Ertel et al. 2014, 12 to 30% of stars)

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